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DESCRIPTION

ANTENNA APPARATUS AND TRANSMITTER/RECEIVER

Technical Field

The present invention relates to an antenna apparatus suitable for use in scanning with high-frequency electromagnetic waves (high-frequency signals), such as micro waves and millimeter waves, over a predetermined angular range, and a transmitter/receiver, such as a radar and a communication apparatus, constructed using the antenna apparatus.

Background Art

In general, various kinds of beam-scanning antenna apparatuses used for an on-vehicle radar, for example, have been known. For example, a first conventional technique has been known in that a reciprocal first dielectric line and a second fixed dielectric line constitute a directional coupler while the first dielectric line having a primary radiator connected to move together (Japanese Unexamined Patent Application Publication No. 2001-217634, for example).

Also, a second conventional technique has been known in that a reflection plate for reflecting a beam radiated from the primary radiator is rotated in accordance with the beam

scanning angle using a rotation mechanism, and an antenna transmitter/receiver including the primary radiator is allowed for beam scanning using a cam mechanism or a link mechanism (Japanese Unexamined Patent Application Publication No. 11-27036, Japanese Unexamined Patent Application Publication No. 11-38132, for example).

Furthermore, a third conventional technique has also been known in that a dielectric disc provided in front of a transmitter/receiver antenna with thicknesses different with a circumferential angle is rotated, and a hollow dielectric cylinder with an inclined axis arranged around a waveguide slot array is rotated (Japanese Unexamined Patent Application Publication No. 10-300848, Japanese Unexamined Patent Application Publication No. 6-334426, for example).

However, in the antenna apparatus according to the first conventional techniq1ue mentioned above, in addition to the necessity for a reciprocal mechanism, such as a linear motor, for reciprocating the primary radiator, etc., it is required to accelerate/decelerate the primary radiator, etc., along with the reciprocation of the primary radiator, so that the increased mechanical load to the reciprocal mechanism becomes a problem.

Also, in the second conventional technique, while the cam mechanism and the link mechanism required for beam scanning are mechanically complicated, so that the entire

antenna apparatus is liable to increase in size, and the layout of the entire antenna apparatus is complicated because of the arrangement of the cam mechanism, etc., increasing manufacturing cost.

Furthermore, in the third technique, by rotating the dielectric disc or the dielectric cylinder, the direction of a beam passing through the dielectric cylinder, etc., is changed; however, since the direction of the primary radiator, etc., is not directly changed, the dielectric cylinder, etc., tends to increase in size. Hence, there arises a problem that the load to a motor or the like for rotating the dielectric cylinder is increased, reducing reliability and durability.

The present invention has been made in view of the problems of the conventional techniques described above, and it is an object thereof to provide an antenna apparatus and its transmitter/receiver capable of reducing a mechanical load as well as manufacturing cost by simplifying a structure.

Disclosure of Invention

In order to achieve the object described above, an antenna apparatus according to the present invention includes a fixed-side transmission line having an electric field distribution or a magnetic field distribution axially

symmetrical in a propagating direction; a rotation-side transmission line, having an axially symmetrical electric field distribution or magnetic field distribution, arranged coaxially with the fixed-side transmission line so as to be rotatable about the axis of the fixed-side transmission line; a transmission-line side choke disposed between the fixed-side transmission line and the rotation-side transmission line for causing short-circuit between both the lines at a high frequency; and a primary radiator disposed in the rotation-side transmission line in a state rotatable together with the rotation-side transmission line for radiating high-frequency signals that have passed through the rotation-side transmission line in a direction different from that of the rotation axis of the rotation-side transmission line.

By such a configuration, the fixed-side transmission line is arranged coaxially with the rotation-side transmission line, and both the lines have an axially symmetrical electric field distribution or magnetic field distribution, so that high-frequency signals in the same mode can be propagated through the fixed-side transmission line and the rotation-side transmission line regardless of the rotational displacement of the rotation-side transmission line. Between the fixed-side transmission line and the rotation-side transmission line, the transmission-

line side choke is provided, so that both the lines can be choke-coupled together and short-circuited at a high-frequency using the transmission-line side choke so as to prevent the high-frequency signal from leaking from the gap between both the lines.

Furthermore, the rotation-side transmission line is provided with the primary radiator radiating high-frequency signals in a direction different from the rotation axis, so that using the primary radiator, the high-frequency signal can be radiated in a direction such as a perpendicular direction and a direction inclined by a predetermined angle relative to the radiating direction of the rotation-side transmission line. Also, since the primary radiator is rotated together with the rotation-side transmission line, the entire circumstance can be scanned with high-frequency signals about the rotation axis while the high-frequency signals can be radiated over an arbitrary angular range through the primary radiator by blocking an unnecessary radiation range as long as the range is within 360° (whole circumference). When the antenna apparatus according to the present invention is applied to a radar, for example, while wide angle detection is possible over the whole circumference, angular resolution can be improved because of the detection at an arbitrary angle.

According to the preferred embodiment of the present

invention, a plurality of the primary radiators are provided in the rotation-side transmission line, and the plurality of the primary radiators are arranged to direct themselves in directions different from each other.

Therefore, a plurality of primary radiators can be radially arranged about the rotation axis. At this time, when the primary radiators directed in a predetermined direction in the plurality of rotating primary radiators are radiated while residual primary radiators are blocked, while the rotation-side transmission line is making one revolution, a plurality of the primary radiators are directed in a predetermined direction. As a result, in comparison with the single primary radiator attached thereto, a period of time radiating the high-frequency signals in a predetermined direction within one revolution can be increased so as to increase the detection period and communication period.

Moreover, according to the preferred embodiment of the present invention, a casing is provided around the plurality of the primary radiators for surrounding the primary radiators, and the casing is provided with a radiator opening formed thereon, to which any one of the plurality of rotating primary radiators is sequentially connected.

Thereby, while high-frequency signals are radiated through the radiator opening of the casing from one primary radiator sequentially connected thereto, residual primary

radiators are surrounded by the casing so that the radiation of the high-frequency signals can be blocked. Since while the rotation-side transmission line is making one revolution, a plurality of the primary radiators are sequentially connected to the radiator opening, in comparison with the single primary radiator attached thereto, a period of time radiating the high-frequency signals through the radiator opening within one revolution of the rotation-side transmission line can be increased so as to increase the detection period and communication period.

Moreover, according to the preferred embodiment of the present invention, a radiator-side choke is provided between the plurality of primary radiators and the casing, and when one of the primary radiators is connected to the radiator opening, the residual primary radiators and the casing are shorted therebetween by the radiator-side choke at high frequency.

Thereby, while one primary radiator is radiating high-frequency signals through the radiator opening, the high-frequency signals can be suppressed from leaking through between the residual primary radiators and the casing, so that the loss of the entire antenna apparatus can be suppressed.

According to the preferred embodiment of the present invention, an antenna apparatus includes a fixed-side

transmission line having an electric field distribution or a magnetic field distribution axially symmetrical in a propagating direction; a rotation-side transmission line, having an axially symmetrical electric field distribution or magnetic field distribution, arranged coaxially with the fixed-side transmission line so as to be rotatable about the axis of the fixed-side transmission line; a transmission-line side choke disposed between the fixed-side transmission line and the rotation-side transmission line for causing short-circuit between both the lines at a high frequency; and a primary radiator disposed in the rotation-side transmission line in a state rotatable together with the rotation-side transmission line for radiating high-frequency signals that have passed through the rotation-side transmission line in parallel with the rotation axis of the rotation-side transmission line not coaxially with the rotation axis.

Thereby, the fixed-side transmission line is choke-coupled with the rotation-side transmission line using the transmission-line side choke, so that high-frequency signals can be propagated through the two transmission lines. Also, the rotation-side transmission line is provided with the primary radiator capable of radiating high-frequency signals in parallel with the rotation axis not coaxially with the rotation axis, so that the radiation position of the high-

frequency signal can be moved about the rotation axis as a center by rotating the primary radiator together with the rotation-side transmission line.

According to the preferred embodiment of the present invention, a secondary radiator is arranged on the line of the radiating direction of the primary radiator, and the secondary radiator changes an outgoing radiation direction in accordance with an incident position of high-frequency signals.

Thereby, by rotating the primary radiator together with the rotation-side transmission line, the incident position of high-frequency signals can be moved relative to the secondary radiator made of a dielectric lens, a bifocal lens, or a parabola reflector so as to change the outgoing direction of the high-frequency signal emitted from the secondary radiator. As a result, scanning can be carried out laterally on a horizontal plane or scanning can be performed in a conical shape with a beam.

According to the preferred embodiment of the present invention, the respective fixed-side transmission line and the rotation-side transmission line are made of a circular waveguide having a propagation mode in a TM01 mode as the magnetic field distribution axially symmetrical about the propagating direction.

Thereby, the fixed-side transmission line or the

rotation-side transmission line can be easily connected to a rectangular waveguide in the TE10 mode, for example, so as to easily feed high-frequency signals to the fixed-side transmission line while the rotation-side transmission line can be readily connected to the primary radiator such as a horn antenna.

Also, a transmitter/receiver, such as a radar and a communication apparatus, may be constructed using the antenna apparatus according to the present invention.

Brief Description of the Drawings

Fig. 1 is a perspective view of an antenna apparatus according to a first embodiment.

Fig. 2 is an exploded perspective view of the antenna apparatus according to the first embodiment.

Fig. 3 is a longitudinal sectional view of the antenna apparatus viewed in arrow direction III-III of Fig. 1.

Fig. 4 is a cross-sectional view of a rotation-side circular waveguide viewed in arrow direction IV-IV of Fig. 3.

Fig. 5 is a plan view of a fixed-side circular waveguide viewed in arrow direction V-V of Fig. 3.

Fig. 6 is a characteristic diagram showing the relationship between the inner diameter and the blocking or cut-off frequency of a circular waveguide.

Fig. 7 is a characteristic diagram showing frequency

characteristics of the reflection factor and the transmission factor between a rectangular waveguide and the fixed-side circular waveguide.

Fig. 8 is a characteristic diagram showing frequency characteristics of the reflection factor and the transmission factor between the fixed-side circular waveguide and the rotation-side circular waveguide.

Fig. 9 is a longitudinal sectional view of an antenna apparatus according to a first modification viewed from the same position as that of Fig. 3.

Fig. 10 is a perspective view of an antenna apparatus according to a second embodiment shown in a state in that a casing is removed.

Fig. 11 is a longitudinal sectional view of the antenna apparatus viewed in arrow direction XI-XI of Fig. 10.

Fig. 12 is a cross-sectional view of a rotation-side circular waveguide and the casing viewed in arrow direction XII-XII of Fig. 11.

Fig. 13 is a longitudinal sectional view of an antenna apparatus according to a third embodiment viewed from the same position as that of Fig. 3.

Fig. 14 is a perspective view of a rotation-side circular waveguide according to the third embodiment shown in a single unit.

Fig. 15 is a longitudinal sectional view of an

essential part of the rotation-side circular waveguide in Fig. 13.

Fig. 16 is a cross-sectional view of the rotation-side circular waveguide and the casing viewed in arrow direction XVI-XVI of Fig. 13.

Fig. 17 is a characteristic diagram showing frequency characteristics of the reflection factor and the transmission factor between a primary radiator and the rotation-side circular waveguide.

Fig. 18 is a perspective view of a rotation-side circular waveguide according to a second modification shown in a single unit.

Fig. 19 is a perspective view of a rotation-side circular waveguide according to a third modification shown in a single unit.

Fig. 20 is a cross-sectional view of a rotation-side circular waveguide and a casing according to a fourth modification at the same position as that of Fig. 16.

Fig. 21 is a plan view of an antenna apparatus according to a fourth embodiment.

Fig. 22 is a characteristic diagram showing the relationship between the beam scanning angle and the antenna gain of the antenna apparatus shown in Fig. 21.

Fig. 23 is a sectional view of an antenna apparatus according to a fifth modification.

Fig. 24 is a plan view of an antenna apparatus according to a sixth modification.

Fig. 25 is a block diagram of a radar according to a fifth embodiment.

Fig. 26 is a block diagram of a radar according to a seventh modification.

Best Mode for Carrying Out the Invention

An antenna apparatus and a transmitter/receiver according to an embodiment of the present invention will be described below in detail with reference to the attached drawings.

First, Figs. 1 to 8 show the antenna apparatus according to a first embodiment and its various frequency characteristics.

In the drawings, reference numeral 1 denotes a fixed-side circular waveguide as a cylindrical fixed-side transmission line axially symmetrical about an axis O, and the fixed-side circular waveguide 1 is provided with a circular hole 1A perforated with a circular section and extending in an axial direction. The fixed-side circular waveguide 1 has a propagation mode in a TM01 mode as a magnetic field distribution axially symmetrical (rotationally symmetrical) about a transmission direction (axial direction) of high-frequency signals, for example.

The inner diameter ϕ of the circular hole 1A herein is established to have a value that allows to pass through the TM01 mode with a desired frequency in a sufficiently low loss state and blocks the next higher-order mode (TE21 mode). For example, in blocking or cut-off frequency characteristics versus the inner diameter ϕ shown in Fig. 6, when the inner diameter ϕ is less than 3.5 mm, the TE21 mode with 83 GHz or less can be blocked while when the inner diameter ϕ is larger than 3.3 mm, the TM01 mode with 68 GHz or more can be allowed to pass through. Hence, it is understood that when the desired frequency is in a 76 GHz band used for an on-vehicle millimeter wave radar, the inner diameter ϕ be established 3.4 mm as an intermediate value between 3.3 mm and 3.5 mm, for example.

Reference numeral 2 denotes a rectangular waveguide connected to the fixed-side circular waveguide 1, and one end of the rectangular waveguide 2 is attached to one end (lower end in Fig. 1) of the fixed-side circular waveguide 1 while the other end of the rectangular waveguide 2 extending outside in a radial direction of a circle with center at an axis O. The rectangular waveguide 2 is provided with a rectangular hole 2A extending in a longitudinal direction (radial direction), and the rectangular hole 2A has a rectangular section with a height L1 and a width L2. The rectangular waveguide 2 is also provided with a

substantially rectangular connection hole 2B formed adjacent to the one end at a position opposing the circular hole 1A of the fixed-side circular waveguide 1 with a width L2 and a length L3, and the rectangular hole 2A and the circular hole 1A are communicated with together through the connection hole 2B. Furthermore, around the connection hole 2B, a back short part 2C is formed to include a concavity sunken lower than the bottom of the rectangular hole 2A by a depth L4 as a space distance larger than other portions in the axial direction of the fixed-side circular waveguide 1.

The rectangular waveguide 2 also has a propagation mode in a TE10 mode with electric field distribution parallel with the axial direction of the fixed-side circular waveguide 1 and vertical and annular magnetic field distribution, for example. Then, the rectangular waveguide 2 is magnetically coupled with the fixed-side circular waveguide 1 through the connection hole 2B, so that the TE10 mode is converted into the TM01 mode. The part between the two waveguides 1 and 2 performs as a mode conversion part with the back short part 2C.

As an exemplification, when the height L1 of the rectangular hole 2A is 1.27 mm; the width L2 is 2.54 mm; the length L3 of the connection hole 2B and the back short part 2C is 3.4 mm; and the depth L4 of the back short part 2C is 1.0 mm, frequency characteristics of the reflection

coefficient and the transmission coefficient between the rectangular waveguide 2 and the fixed-side circular waveguide 1 are shown in Fig. 7. As a result, it is understood that high-frequency signals at an around 76 GHz band can be transmitted in a low reflected state.

Reference numeral 3 denotes a rotation-side circular waveguide as an axially symmetrical and cylindrical rotation-side circular waveguide 1, which is provided with a circular hole 3A circular in cross-section with substantially the same inner diameter ϕ as that of the circular hole 1A of the fixed-side circular waveguide 1 and extending in an axial direction, and the circular hole 3A extends to a halfway position in the axial direction. The rotation-side circular waveguide 3 is spaced from the fixed-side circular waveguide 1 by a space $\delta 1$ while being coaxially arranged along the axis O of the fixed-side circular waveguide 1 and rotatable about the axis O along the entire circumference using a motor 7, which will be described later.

One end (lower end in Fig. 1) of the rotation-side circular waveguide 3 opposes the other end of the fixed-side circular waveguide 1 in a state that the circular hole 3A opposes the circular hole 1A. On the other hand, the other end (upper end in Fig. 1) of the rotation-side circular waveguide 3 is closed with a circular disc-like lid 3B while

being attached in a state having a primary radiator 5 built therein, which will be described later.

The rotation-side circular waveguide 3 herein has a propagation mode in a TM01 mode with magnetic field distribution axially symmetrical (rotationally symmetrical) about the transmission direction (axial direction) of high-frequency signals, for example, as the same propagation mode as that of the fixed-side circular waveguide 1. Then, the rotation-side circular waveguide 3 is magnetically coupled with the fixed-side circular waveguide 1 so that the high-frequency signals in the TM01 mode are transmitted therethrough.

Reference numeral 4 denotes a waveguide-side choke provided in the fixed-side circular waveguide 1 at a position between the fixed-side circular waveguide 1 and the rotation-side circular waveguide 3 as a transmission line-side choke. The waveguide-side choke 4 is formed of a substantially ring-shaped circular groove. The waveguide-side choke 4 is also spaced from the outermost periphery of the circular hole 1A by a space L5.

Furthermore, the waveguide-side choke 4 having a width L6 and a depth L7 is concavely formed on an open end-face of the fixed-side circular waveguide 1 opposing the rotation-side circular waveguide 3. Thereby, the waveguide-side choke 4 virtually shorts portions (portion "a" in Fig. 3) in

the vicinity of the outermost peripheries of the circular holes 1A and 3A of the circular waveguides 1 and 3.

As an exemplification, when space δ1 between the circular waveguides 1 and 3 is 0.15 mm; the space L5 is 0.5 mm; the width L6 of the waveguide-side choke 4 is 1.0 mm; and the depth L7 thereof is 1.5 mm, frequency characteristics of the reflection coefficient and the transmission coefficient between the circular waveguides 1 and 3 are shown in Fig. 8. As a result, it is understood that high-frequency signals at an around 76 GHz band can be transmitted in a low reflected state.

Reference numeral 5 denotes a primary radiator attached to the rotation-side circular waveguide 3 in a built-in state. The primary radiator 5 having a rectangular section, for example, is formed of a waveguide horn antenna gradually expanding radially to the outside. The endextremity of the primary radiator 5 herein is opened on the side face of the rotation-side circular waveguide 3. Thereby, the primary radiator 5 can radiate a high-frequency signal beam in a direction perpendicular to the axis O, for example, as a direction different from the rotational axis (axis O). On the other hand, the base end of the primary radiator 5 is connected to a rectangular waveguide part 6 formed of a rectangular hole radially extending with a rectangular section.

The rectangular waveguide part 6 is provided with a substantially rectangular connection hole 6A formed at a position opposing the circular hole 3A of the rotation-side circular waveguide 3, and having a shape similar to the rectangular hole 2A of the rectangular waveguide 2, for example, and extending to the other end (upper end in Fig. 1) of the circular hole 3A of the rotation-side circular waveguide 3. The rectangular waveguide part 6 is communicated with the circular hole 3A through the connection hole 6A. Furthermore, around the connection hole 6A, there is provided a back short part 6B with a space larger than other portions in the axial direction of 3 so as to have a shape similar to the back short part 2C, for example.

The rectangular waveguide part 6 has a propagation mode in a TM01 mode, for example, and is magnetically coupled with the rotation-side circular waveguide 3 through the connection hole 2B while a matched state is maintained between the rectangular waveguide part 6 and the rotation-side circular waveguide 3 by the back short part 6B.

Reference numeral 7 denotes a motor attached to the lid 3B of the rotation-side circular waveguide 3. The motor 7, together with the fixed-side circular waveguide 1 for example, is fixed to a casing (not shown), etc., so as to continuously rotate the rotation-side circular waveguide 3

about the axis O in all directions.

The waveguide according to the embodiment has the configuration described above, and then, its operation will be described.

First, upon inputting high-frequency signals, such as millimeter waves, into the rectangular waveguide 2, the high-frequency signals are propagated through the rectangular waveguide 2 in the TE10 mode so as to reach the connection hole 2B. At this time, the rectangular waveguide 2 is coupled with the fixed-side circular waveguide 1 through the connection hole 2B, so that the high-frequency signals are converted into the TM01 mode from the TE10 mode, and are propagated through the fixed-side circular waveguide 1. Since the fixed-side circular waveguide 1 is arranged coaxially with the rotation-side circular waveguide 3, the high-frequency signals in the axially symmetrical TM01 mode are propagated through the rotation-side circular waveguide 3 regardless of the rotational displacement of the rotation-side circular waveguide 3. Also, since the rotation-side circular waveguide 3 is connected to the primary radiator 5 via the rectangular waveguide part 6, the high-frequency signals are radiated outside from the primary radiator 5.

Still, according to the embodiment, the fixed-side circular waveguide 1 is arranged coaxially with the rotation-side circular waveguide 3, and both the waveguides

have an axially symmetrical propagation mode in the TM01 mode, so that high-frequency signals can be propagated through the fixed-side circular waveguide 1 and the rotation-side circular waveguide 3 regardless of the rotational displacement of the rotation-side circular waveguide 3.

Between the fixed-side circular waveguide 1 and the rotation-side circular waveguide 3, the waveguide-side choke 4 is provided, so that both the waveguides are choke-coupled together and short-circuited at a high-frequency using the waveguide-side choke 4 so as to prevent the high-frequency signal from leaking from the gap between both the waveguides.

Furthermore, since the rotation-side circular waveguide 3 is provided with the primary radiator 5 that can radiate a high-frequency signal in a direction different from the rotational axis, the high-frequency signal can be radiated using the primary radiator 5 in a direction perpendicular to the propagation direction of the rotation-side circular waveguide 3. Because the primary radiator 5 is constructed to rotate in conjunction with the rotation-side circular waveguide 3, while the whole circumference can be scanned with high-frequency signals about the rotational axis, the high-frequency signal can be radiated over an arbitrary angular range through the primary radiator by blocking an unnecessary radiation range, such as a semicircle, using a

casing as long as the range is within 360° (whole circumference).

Also, when the antenna apparatus according to the present invention is applied to a radar, while wide angle detection is possible over the whole circumference, angular resolution can be improved because of the detection at an arbitrary angle.

Furthermore, according to the embodiment, the rotation-side circular waveguide 3 is rotated in a predetermined direction (constant-speed rotation) using the motor 7, so that the constant-acceleration rotation, such as reciprocal movement, is not necessary unlike in a conventional technique so as to reduce the mechanical load to the driving system (the motor 7), improving reliability and durability.

Also, the entire antenna apparatus has a simplified structure composed of the two circular waveguides 1 and 3 so as to be easily manufactured by cutting and injection molding, reducing manufacturing cost.

Furthermore, since the circular waveguides 1 and 3 having a propagation mode in the TM01 mode are used, the fixed-side circular waveguide 1 or the rotation-side circular waveguide 3 can be easily connected to the rectangular waveguide 2 in the TE10 mode, for example, so as to easily feed high-frequency signals to the fixed-side circular waveguide 1 while the rotation-side circular

waveguide 3 can be readily connected to the primary radiator 5 such as a horn antenna.

In addition, according to the first embodiment, high-frequency signals are propagated through the circular waveguides 1 and 3 in the TM01 mode; however, any high-frequency signals in a mode, in which electric field distribution or magnetic field distribution is axially symmetrical, may be propagated, so that high-frequency signals in other modes, such as the TE01 mode and a coaxial TEM mode, may also be propagated.

Also, according to the first embodiment, the waveguide-side choke is constructed of the waveguide-side choke 4 composed of the ring-shaped groove surrounding the circular hole 1A; however, the present invention is not limited to this so that the waveguide-side choke may also be constructed of any choke composed of a polygonal groove, such as a triangular or square groove, as long as the groove surrounds the circular hole.

According to the first embodiment, the waveguide-side choke 4 is arranged on the opened end face of the fixed-side circular waveguide 1; alternatively, the waveguide-side choke may be arranged on the opened end face of the rotation-side circular waveguide 3, or the waveguide-side chokes may also be provided on both the circular waveguides 1 and 3.

According to the first embodiment, the primary radiator 5 radiates a high-frequency signal beam in a direction perpendicular to the rotational axis (the axis O) of the rotation-side circular waveguide 3; however, the present invention is not limited to this, so that if the high-frequency signal beam can be outside radiated radially from the rotational axis, the high-frequency signal beam may also be radiated in a direction inclined by an angle α relative to the rotational axis, as shown in Fig. 3, by attaching the primary radiator to be inclined.

According to the first embodiment, the primary radiator 5 is composed of the waveguide horn antenna with a rectangular section; however, the present invention is not limited to this, so that the primary radiator may have other sections, such as a circular or elliptical section, so as to appropriately establish antenna characteristics, such as an antenna gain, a sidelobe level, and a beam width, responding to various demands. Moreover, the primary radiator is not limited to the waveguide horn antenna, so that other antenna devices, such as a microstrip antenna, may also be used.

Also, according to the first embodiment, the rotation-side circular waveguide 3 and the primary radiator 5 are connected together via the rectangular waveguide part 6; however, the present invention is not limited to this, so that a primary radiator 8 may also be directly connected to

a part way of a circular hole 3A' like in a first modification shown in Fig. 9.

Moreover, according to the first embodiment, the primary radiator 5 is attached to the rotation-side circular waveguide 3 in a built-in state; alternatively, the primary radiator 5 may be attached to the side face of the rotation-side circular waveguide 3 to protrude therefrom by extending the rectangular waveguide part 6 to the side face (external periphery) of the rotation-side circular waveguide 3.

Next, Figs. 10 to 12 show an antenna apparatus according to a second embodiment of the present invention. A feature of the embodiment is that a rotation-side circular waveguide is provided with two primary radiators attached thereto. In addition, according to the embodiment, like reference characters designate like components common to the first embodiment and the description thereof is omitted.

Reference numeral 11 denotes a rotation-side circular waveguide according to the second embodiment. The rotation-side circular waveguide 11 is formed to have an axially symmetrical and cylindrical shape similar to the rotation-side circular waveguide 3 according to the first embodiment. Also, the rotation-side circular waveguide 11 is provided with a circular hole 11A perforated with a circular section with substantially the same inner diameter as the circular hole 1A of the fixed-side circular waveguide 1 and extending

in an axial direction. The circular hole 11A extends to a halfway position in the axial direction, so that high-frequency signals can be propagated in the TM01 mode.

The rotation-side circular waveguide 11 is spaced from the fixed-side circular waveguide 1 by a space of about 0.15 mm while being arranged coaxially with the axis O of the fixed-side circular waveguide 1 and rotatable over the whole circumference about the axis O by a motor 16, which will be described later.

One end (lower end in Fig. 10) of the rotation-side circular waveguide 11 opposes the other end of the fixed-side circular waveguide 1, and the other end (upper end in Fig. 10) of the rotation-side circular waveguide 11 is closed with a disc-like lid 11B. The rotation-side circular waveguide 11 is magnetically coupled with the fixed-side circular waveguide 1 and high-frequency signals are propagated between the waveguides in the TM01 mode.

Reference numeral 12 denotes two primary radiators attached to the rotation-side circular waveguide 11 in a built-in state. Each primary radiator 12 is formed of a waveguide horn antenna in a manner similar to the primary radiator 5 according to the first embodiment. The two primary radiators 12 are radially arranged in directions different from each other from the rotational axis (the axis O) as a center, opposite to each other, for example. The

endextremity of the primary radiator 12 is opened on the side face of the rotation-side circular waveguide 11. On the other hand, the base end of the primary radiator 12 radially extends to be connected to a rectangular waveguide part 13 with a propagation mode in the TE10 mode.

The rectangular waveguide part 13 is provided with a substantially rectangular connection hole 13A formed at a position opposing the circular hole 11A of the rotation-side circular waveguide 11 and extending to the other end (upper end in Fig. 10) of the circular hole 11A of the rotation-side circular waveguide 11. Furthermore, around the connection hole 13A, a back short part 13B is formed to have a space distance larger than other portions in the axial direction of the rotation-side circular waveguide 11.

Reference numeral 14 denotes a casing provided to surround the circular waveguides 1 and 11, and the casing 14 is composed of a cylinder portion 14A fixed to the fixed-side circular waveguide 1 and the rectangular waveguide 2 so as to cover the external periphery of the rotation-side circular waveguide 11, and a top board portion 14B arranged at the upper end of the cylinder portion 14A so as to cover the lid 11B of the rotation-side circular waveguide 11. The cylinder portion 14A is provided with an accommodation hole 14C formed inside so as to accommodate the rotation-side circular waveguide 11 therein to have a gap $\delta 2$ of about 0.15

mm to the external surface of the rotation-side circular waveguide 11.

Reference numeral 15 denotes a radiator opening formed in the cylinder portion 14A, and the radiator opening 15, as shown in Fig. 12, is penetrated at a position (opposable position) corresponding to the primary radiator 12. The radiator opening 15 has an area greater than that of the opening of the primary radiator 12, and is opened over an angular range β about the rotational axis (the axis O) of the rotation-side circular waveguide 11. The radiator opening 15 is connected to the two primary radiators 12 rotating together with the rotation-side circular waveguide 11 sequentially from any one of the two radiators.

Reference numeral 16 denotes a motor fixed to the top board portion 14B of the casing 14. The rotational axis of the motor 16 is attached to the lid 11B of the rotation-side circular waveguide 11 so as to continuously rotate the rotation-side circular waveguide 11 about the axis O in all directions by the motor 16.

In such a manner, according to the embodiment, the same effects and advantages as those of the first embodiment can also be obtained. Moreover, according to the embodiment, while the two primary radiators 12 arranged in directions opposite to each other are provided in the rotation-side circular waveguide 11, the respective primary radiators 12

are sequentially connected to the radiator opening 15 of the casing 14 along with the rotation of the rotation-side circular waveguide 11, so that while one of the primary radiators 12 are radiating high-frequency signals, the other is surrounded by the casing 14 so that the radiation of the high-frequency signals can be blocked. Thereby, while the rotation-side circular waveguide 11 is making one revolution, the two primary radiators 12 are connected to the radiator opening 15 so as to radiate the high-frequency signals, so that in comparison with the single primary radiator attached thereto, a period of time radiating the high-frequency signals in a predetermined direction through the radiator opening 15 within one revolution can be increased so as to increase the detection period and communication period.

In particular, when the angle β of the radiator opening 15 is established to be 180°, any one of the two primary radiators 12 arranged in directions opposite to each other across the rotational axis as the center is always connected to the radiator opening 15, so that detection or communication can be always carried out.

According to the embodiment, the two primary radiators 12 are attached to the rotation-side circular waveguide 11; alternatively, three or more primary radiators may be attached. While a plurality of primary radiators are arranged at equal intervals (120° intervals when the

radiators are three, for example) in the circumferential direction about the rotational axis of the rotation-side circular waveguide as the center, in accordance with the intervals, the angular range (120° intervals when the radiators are three, for example) of the radiator opening of the casing may be established. Also, a plurality of primary radiators may be arranged at different intervals in the circumferential direction about the rotational axis of the rotation-side circular waveguide as the center.

Furthermore, according to the embodiment, the two primary radiators 12 are radially arranged about the rotational axis of the rotation-side circular waveguide 11 as the center; however, they may be arranged in different directions from each other, and they may be spirally arranged for example.

Next, Figs. 13 to 17 show an antenna apparatus and frequency characteristics regarding the antenna apparatus according to a third embodiment of the present invention. A feature of the embodiment is that while a rotation-side circular waveguide is provided with two primary radiators attached thereto, a radiator-side choke is provided around an open end of each primary radiator. In addition, according to the embodiment, like reference characters designate like components common to the first embodiment and the description thereof is omitted.

Reference numeral 21 denotes a rotation-side circular waveguide according to the third embodiment. The rotation-side circular waveguide 21 is formed to have an axially symmetrical and cylindrical shape similar to the rotation-side circular waveguide 3 according to the first embodiment. Also, the rotation-side circular waveguide 21 is provided with a circular hole 21A perforated with a circular section with substantially the same inner diameter as the circular hole 1A of the fixed-side circular waveguide 1 and extending in an axial direction. The circular hole 21A extends to a halfway position in the axial direction.

The rotation-side circular waveguide 21 is spaced from the fixed-side circular waveguide 1 by a space of about 0.15 mm while being arranged coaxially with the axis O of the fixed-side circular waveguide 1 and rotatably about the axis O. One end of the rotation-side circular waveguide 21 has the circular hole 21A opened therefrom, and the other end of the rotation-side circular waveguide 21 is closed with a disc-like lid 21B. Furthermore, the rotation-side circular waveguide 21 is surrounded with a casing 25, which will be described later, and spaced from the casing 25 by a space $\delta 2$. The rotation-side circular waveguide 21 is magnetically coupled with the fixed-side circular waveguide 1 and high-frequency signals are propagated between the waveguides in the TM01 mode.

Reference numeral 22 denotes two primary radiators attached to the rotation-side circular waveguide 21 in a built-in state. Each primary radiator 22 is formed of a waveguide horn antenna gradually expanding at an expanding angle φ in a manner similar to the primary radiator 5 according to the first embodiment. The two primary radiators 22 are radially arranged in directions different from each other from the rotational axis (the axis O) as a center at equal intervals in the circumferential direction (directions opposite to each other). The endextremity of each primary radiator 22 is opened on the side face of the rotation-side circular waveguide 21. On the other hand, the base end of the primary radiator 22 radially extends to be connected to a rectangular waveguide part 23 with a propagation mode in the TE10 mode.

The rectangular waveguide part 23 is provided with a substantially rectangular connection hole 23A formed at a position opposing the circular hole 21A of the rotation-side circular waveguide 21 so as to have substantially the same size as that of the rectangular hole 2A of the rectangular waveguide 2 according to the first embodiment and to extend to the other end of the circular hole 21A of the rotation-side circular waveguide 21. Furthermore, around the connection hole 23A, a back short part 23B is formed for matching the rotation-side circular waveguide 21 (the

circular hole 21A) with the rectangular waveguide part 23.

Reference numeral 24 denotes a radiator-side choke provided in the rotation-side circular waveguide 21 to surround the open end of the primary radiator 22, and two radiator-side chokes 24 are formed on the external surface of the rotation-side circular waveguide 21 corresponding to the two respective primary radiators 22, and are composed of substantially elliptical (substantially rectangular) grooves. Also, the radiator-side choke 24 is arranged at a position spaced from the center of the open end of the primary radiator 22 by a space L8.

Furthermore, the radiator-side choke 24 has a width L9 and a depth L10, and is concavely arranged on the external surface of the rotation-side circular waveguide 21. Thereby, the radiator-side choke 24 virtually shorts between the vicinity of the open end of the primary radiator 22 and the casing 25 which will be described later.

As an exemplification, when one primary radiator 22 is opposed (blocked) to the casing 25 and the other is opened (capable of radiating), frequency characteristics of the reflection factor and the transmission factor between the other primary radiator 22 and the rotation-side circular waveguide 21 are shown in Fig. 17. Where the expanding angle φ of the primary radiator 22 is 0°; the space $\delta 2$ between the rotation-side circular waveguide 21 and the

casing 25 is 0.15 mm; the space L8 is 1.7 mm; the width L9 of the radiator-side choke 24 is 1.0 mm; the depth L10 is 1.2 mm; the distance L11 from the rotational axis to the open end of the primary radiator 22 is 4.5 mm; the length L12 of the back short part 23B is 3.4 mm; and the height L13 of the back short part 23B is 0.8 mm. As a result, it is understood that high-frequency signals at an about 76 GHz band can be transmitted in a low reflection state.

Reference numeral 25 denotes a casing provided to surround the circular waveguides 1 and 21, and the casing 25 is composed of a cylinder portion 25A fixed to the fixed-side circular waveguide 1 and the rectangular waveguide 2 so as to cover the external periphery of the rotation-side circular waveguide 21, and a top board portion 25B arranged at the upper end of the cylinder portion 25A so as to cover the lid 21B of the rotation-side circular waveguide 21. The cylinder portion 25A is provided with an accommodation hole 25C formed inside so as to accommodate the rotation-side circular waveguide 21 therein.

Reference numeral 26 denotes a radiator opening formed in the cylinder portion 25A, and the radiator opening 26, as shown in Fig. 16, is penetrated at a position (opposable position) corresponding to the primary radiator 22. The radiator opening 26 has an area greater than that of the opening of the primary radiator 22, and is opened over a

predetermined angular range about the rotational axis (the axis O) of the rotation-side circular waveguide 21. The radiator opening 26 is connected to the two primary radiators 22 rotating together with the rotation-side circular waveguide 21 sequentially from any one of the two radiators.

Reference numeral 27 denotes a motor fixed to the top board portion 25B of the casing 25. The rotational axis of the motor 27 is attached to the lid 21B of the rotation-side circular waveguide 21 so as to continuously rotate the rotation-side circular waveguide 21 about the axis O in all directions by the motor 27.

In such a manner, according to the embodiment, the same effects and advantages as those of the first and the second embodiment can also be obtained. Moreover, according to the embodiment, while the two primary radiators 22 arranged in directions opposite to each other are provided in the rotation-side circular waveguide 21, the respective primary radiators 22 are sequentially connected to the radiator opening 26 of the casing 25 along with the rotation of the rotation-side circular waveguide 21, so that while one of the primary radiators 22 are radiating high-frequency signals, the other is surrounded by the casing 25 so that the radiation of the high-frequency signals can be blocked.

Since the radiator-side choke 24 is provided on the

external surface of the rotation-side circular waveguide 21 so as to surround the open end of the primary radiator 22 especially according to the embodiment, the open end of one of the two primary radiators 22, which is surrounded with the casing 25, and the casing 25 can be shorted at a high-frequency using the radiator-side choke 24. As a result, while one of the primary radiators 22 is radiating high-frequency signals through the radiator opening 26, the high-frequency signals can be suppressed from leaking through between the residual primary radiator 22 and the casing 25, so that the loss of the entire antenna apparatus can be suppressed.

According to the third embodiment, the radiator-side chokes 24 are provided on the external surface of the rotation-side circular waveguide 21 so as to surround the open end of the respective primary radiators 22; however, the present invention is not limited to this, so that two ring-shaped concave grooves 31A may also be formed to constitute radiator-side chokes 31 on the external surface of the rotation-side circular waveguide 21 above and below the two primary radiators 22 (on both sides in the axial direction) as in a second modification shown in Fig. 18.

As in a third modification shown in Fig. 19, two first ring-shaped concave grooves 32A may be formed on the external surface of the rotation-side circular waveguide 21

above and below the two primary radiators 22 (on both sides in the axial direction) while second straight concave grooves 32B intersecting with the first concave grooves 32A may be formed on the right and left of the primary radiators 22 (on both sides in the circumferential direction) so as to constitute radiator-side chokes 32 of the first and second concave grooves 32A and 32B. In this case, the protrusion length L14 of the second concave groove 32B from the first concave groove 32A may be established about $\lambda/4$ ($L14 \approx \lambda/4$), where λ is the wavelength under vacuum at used frequency band.

Moreover, according to the third embodiment, the radiator-side chokes 24 are provided on the external surface of the cylindrical rotation-side circular waveguide 21; however, the present invention is not limited to this, so that as in a fourth modification shown in Fig. 20, on one face of a rotation-side circular waveguide 21' with a substantial cubic external shape, a primary radiator 22' may be opened while a radiator-side choke 24' may be formed on the same face as on that the primary radiator 22' is opened. In this case, a casing 25' has an accommodation hole 25C' within which the rotation-side circular waveguide 21' with a square section is rotatable. Thereby, the radiator-side choke 24' can be shaped on a plane so that fabrication of the radiator-side choke 24' is facilitated.

According to the third embodiment, the radiator-side chokes 24 are formed on the external surface of the rotation-side circular waveguide 21; alternatively, they may be formed on the accommodation hole 25C of the casing 25 or may be formed on both the rotation-side circular waveguide 21 and the casing 25.

Next, Fig. 21 shows an antenna apparatus according to a fourth embodiment of the present invention. A feature of the embodiment is that in the radiating direction of the primary radiator, a secondary radiator is provided, which can change the radiating direction in accordance with the incident position of high-frequency signals. In addition, according to the embodiment, like reference characters designate like components common to the first embodiment and the description thereof is omitted.

Reference numeral 41 denotes a secondary radiator made of a dielectric lens with a diameter $\phi 1$ and a thickness T arranged on the line of the radiating direction of the primary radiator 5. The secondary radiator 41 is fixed in a state spaced from the rotation-side circular waveguide 3 by a distance L15.

As an exemplification, when the rotation-side circular waveguide 3 is rotated by a rotation angle $\theta 1$, the relationship between the scanning angle $\theta 2$ of the beam radiated from the secondary radiator 41 and the antenna gain

is investigated. The results are shown in Fig. 22. Where, the diameter $\phi 1$ of the secondary radiator 41 is established 90 mm; the thickness T is 18 mm; and the distance L15 is 27 mm. The rotation angle $\theta 1$ is changed from 0° to 60°, as it is 0° when the primary radiator 5 approaches (faces) the secondary radiator 41 at most. As a result, when the rotation angle $\theta 1$ is changed in a range of -30° to +30° ($\theta 1$ = -30° to +30°), the beam scanning angle $\theta 2$ can be changed from -10° to +10° ($\theta 2$ = -10° to +10°) with the antenna gain obtained sufficiently, so that the apparatus is understood to be applicable to an ACC (adaptive cruise control) radar.

In such a manner, according to the embodiment, the same effects and advantages as those of the first embodiment can also be obtained. Moreover, since the secondary radiator 41 is provided on the line of the radiating direction, the incident position of high-frequency signals can be moved relative to the secondary radiator 41 by rotating the primary radiator 5 with the rotation-side circular waveguide 3 together so as to change an outgoing direction of the high-frequency signals emitted from the secondary radiator 41. As a result, scanning can be carried out laterally on a horizontal plane with the high-frequency signals, so that the apparatus can be applied to an ACC radar.

In addition, according to the fourth embodiment, the dielectric lens is used as the secondary radiator 41;

alternatively, as in a fifth modification shown in Fig. 23, a parabola reflector may be used as a secondary radiator 41'. In this case, when the radiating direction of a primary radiator 5' is inclined about the rotation axis of the rotation-side circular waveguide 3 by an angle α ($\alpha = 10°$ to $80°$, for example), the high-frequency signals can be rather easily entered into the secondary radiator 41'.

Furthermore, according to the fourth embodiment, the primary radiator 5 is arranged in a direction different from that of the rotation axis of the rotation-side circular waveguide 3; alternatively, as in a sixth modification shown in Fig. 24, a primary radiator 5" arranged in parallel with the rotation axis not coaxially with the rotation axis may be used. In this case, by the secondary radiator, scanning can be performed with a beam, and when a secondary radiator 41" composed of a bifocal lens is used, scanning can be performed in a conical shape with a beam.

Next, Fig. 25 shows a fifth embodiment of the present invention. A feature of the embodiment is that using the antenna apparatus according to the present invention, a radar is constructed as a transmitter/receiver.

Reference numeral 51 denotes a radar, and the radar 51 is substantially composed of a voltage-controlled oscillator 52, an antenna apparatus 55 according to the first to fourth embodiments and connected to the voltage-controlled

oscillator 52 via an amplifier 53 and a circulator 54, and a mixer 56 connected to the circulator 54 for down-converting the signals received from the antenna apparatus 55 into intermediate-frequency signals IF. Between the amplifier 53 and the circulator 54, a directional coupler 57 is connected, and by the directional coupler 57, power-distributed signals are entered into the mixer 56 as local signals.

The radar according to the embodiment has the structure described above, and the oscillatory signal produced from the voltage-controlled oscillator 52 is amplified by the amplifier 53 and sent from the antenna apparatus 55 via the directional coupler 57 and the circulator 54 as a sending signal. On the other hand, the signal received from the antenna apparatus 55 is entered into the mixer 56 via the circulator 54 while being down-converted using the local signal from the directional coupler 57 so as to be produced as the intermediate-frequency signal IF.

In such a manner, according to the embodiment, since the radar is constructed using the antenna apparatus 55, by rotating the primary radiator of the antenna apparatus 55, high-frequency signals can be sent or received in all directions.

In addition, according to the fifth embodiment, the antenna apparatus 55 has a structure sharing transmitting with receiving; alternatively, like in a seventh

modification shown in Fig. 26, a structure may be employed in that a transmitting antenna apparatus 61 is provided separately from a receiving antenna apparatus 62.

According to the fifth embodiment described above, the radar incorporates the antenna apparatus according to the present invention; alternatively, the antenna apparatus may be applied to a communication apparatus as a transmitter/receiver.

As is described in detail above, according to the present invention, the fixed-side transmission line is arranged coaxially with the rotation-side transmission line and both the lines have an axially symmetrical electric field distribution or magnetic field distribution, so that high-frequency signals in the same mode can be propagated through the fixed-side transmission line and the rotation-side transmission line regardless of the rotational displacement of the rotation-side transmission line. Between the fixed-side transmission line and the rotation-side transmission line, the transmission-line side choke is provided, so that both the lines can be choke-coupled together and short-circuited at a high-frequency using the transmission-line side choke so as to prevent the high-frequency signal from leaking from the gap between both the lines. Furthermore, the rotation-side transmission line is provided with the primary radiator radiating high-frequency

signals in a direction different from the rotation axis, so that using the primary radiator, the high-frequency signal can be radiated in a direction such as a perpendicular direction and a direction inclined by a predetermined angle relative to the radiating direction of the rotation-side transmission line.

Since the primary radiator is constructed to rotate with the rotation-side transmission line together, while wide angle detection and high angular resolution can be achieved, the entire antenna apparatus structure is simplified, reducing manufacturing cost. As the primary radiator can be driven at a constant speed in a predetermined direction together with the rotation-side transmission line, the load of the primary radiator to the driving system can be reduced, improving reliability and durability.

If a plurality of the primary radiators are provided in the rotation-side transmission line, and the plurality of the primary radiators are arranged to direct themselves in directions different from each other, when any primary radiators directed in a predetermined direction in the plurality of the rotating primary radiators are enabled to radiate signals while the residual primary radiators are blocked, in comparison with the single primary radiator attached thereto, a period of time radiating the high-

frequency signals in the predetermined direction within one revolution can be increased so as to increase the detection period and communication period.

Furthermore, when a casing is arranged around the plurality of the primary radiators for surrounding the primary radiators, and the casing is provided with a radiator opening formed thereon, to which any one of the plurality of rotating primary radiators is sequentially connected, in comparison with the single primary radiator attached thereto, a period of time radiating the high-frequency signals through the radiator opening within one revolution of the rotation-side transmission line can be increased so as to increase the detection period and communication period.

Moreover, when a radiator-side choke is provided between the plurality of primary radiators and the casing, while one primary radiator is radiating high-frequency signals through the radiator opening, the high-frequency signals can be suppressed from leaking through between the residual primary radiators and the casing, so that the loss of the entire antenna apparatus can be suppressed.

Furthermore, when the rotation-side transmission line is provided with the primary radiator capable of radiating high-frequency signals in parallel with the rotation axis not coaxially with the rotation axis, the radiation position

of the high-frequency signal can be moved about the rotation axis as a center by rotating the primary radiator together with the rotation-side transmission line. Thereby, by arranging the secondary radiator on the line of the radiating direction of the primary radiator, scanning can be carried out with a high-frequency signal beam, so that the antenna apparatus can be applied to an ACC radar.

Furthermore, when a secondary radiator, which changes an outgoing radiation direction in accordance with an incident position of high-frequency signals, is arranged on the line of the radiating direction of the primary radiator, by rotating the primary radiator together with the rotation-side transmission line, the incident position of high-frequency signals can be moved relative to the secondary radiator so as to change the outgoing direction of the high-frequency signal emitted from the secondary radiator. As a result, scanning can be carried out laterally on a horizontal plane or scanning can be performed in a conical shape with a beam.

Moreover, when the respective fixed-side transmission line and the rotation-side transmission line are made of a circular waveguide having a propagation mode in a TM01 mode, the fixed-side transmission line or the rotation-side transmission line can be easily connected to a rectangular waveguide in a TE10 mode, for example, so as to easily feed

high-frequency signals to the fixed-side transmission line while the rotation-side transmission line can be readily connected to the primary radiator such as a horn antenna.

Furthermore, when a transmitter/receiver is constructed using the antenna apparatus according to the present invention, the entire antenna apparatus structure is simplified so as to reduce manufacturing cost while the load to a driving system for the primary radiator is reduced, improving reliability and durability.

Industrial Applicability

As described above, in the antenna apparatus according to the present invention, while wide angle detection and high angular resolution can be achieved, the entire antenna apparatus structure is simplified so as to reduce manufacturing cost. Thus, the apparatus is suitable for use as a radar, for example, for scanning with high-frequency electromagnetic waves (high-frequency signals), such as micro waves and millimeter waves, over a predetermined angular range.